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Citation for published version (APA):
Mulligan, M., & Clifford, N. J. (2015). Is managing ecosystem services necessary and sufficient to ensure sustainable development? In M. Redclift, & D. Springett (Eds.), *Routledge International Handbook of Sustainable Development* (pp. 179-195). Taylor and Francis Inc.. https://www.routledge.com/Routledge-International-Handbook-of-Sustainable-Development/Redclift-Springett/p/book/9780415838429

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Download date: 04. May. 2023

Is managing ecosystem services necessary and sufficient to ensure sustainable development?

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Refining the concept of Ecosystem Services

Ecosystem services flow from stocks of natural capital and provide benefits to humanity: for example the carbon sequestration of forests that regulates global atmospheric composition and thus climate; the clean, freshwater flowing from natural landscapes and provided to dams and irrigation projects downstream and the flood storage capacity of wetlands that regulates floodwaters upstream of flood-prone urban areas. These services and the natural capital stocks from which they are derived are critical to the life-support functions of the Earth and contribute to human welfare in direct and indirect ways (Costanza et al., 1997). Ecosystem services are variously classified (see Fisher et al., 2009) including by the MEA (2005) into provisioning, regulating, supporting and cultural services. Provisioning services include the provision of food, timber, textiles and water, regulating services provide regulation against hazards (such as floods and droughts). Cultural services are the non-material aesthetic, recreational, spiritual and health benefits provided by nature. Supporting services support the aforementioned through, for example, maintenance of soil fertility. Ecosystem services are considered to be fundamentally dependent upon biodiversity (Hooper et al., 2005; Tilman et al., 2006; Balvanera et al., 2006). The term ecosystem services is thus used for both goods (provisioning services) and services (regulating, cultural and supporting services).

The sustainability of ecosystem service provision is threatened by human impacts on the environment. Whilst these impacts are necessary to provide a number of the provisioning services e.g. agriculture for food, deforestation for timber, these interventions by a given beneficiary can negatively impact the same services available to other beneficiaries or different services provided by the same landscape. These ‘external’ impacts of ecosystem service ‘farming‘ are not accounted for in the economic system that drives most interventions in the environment and, as a result, these interventions can threaten the equity and sustainability of ecosystem service provision. These services have thus undergone various attempts at valuation, including economic valuation (Costanza et al., 1997) in the hope that their value can be better understood and so that ‘market based’ mechanisms (Gómez-Baggethun et al., 2010) can contribute to better and more holistic management of ecosystem services. The cost and futility of replacing the services currently provided ‘for free’ by ‘green’ infrastructure with those engineered using grey infrastructure is often highlighted in this work.

Fundamental to ecosystem services is the understanding that the presence of an ecosystem with a particular suite of processes provides services that lead to benefits by a defined set of beneficiaries. The (mis-) management of these ecosystems can thus affect the benefits received from them now and in the future. This is, of course, very close to the principle that development can be sustainable or otherwise. The Millennium Ecosystem Assessment (2005) concluded that humans have caused significant, irreversible biodiversity loss through extensive and rapid ecosystem alteration for human development in the last 50 years. This has led to improved human wellbeing and economic development for many, but has cost the degradation of many ecosystem services, and this is likely to continue unless ecosystem services management are embedded in environment and development policies, institutions, and practices with a stronger sustainability focus.

Environmental services vs ecosystem services

To date the terms ‘Environmental Services’ and ‘Ecosystem Services’ have been used as synonyms, although Mulligan et al (2013) ascribe specific meaning to each. For Mulligan et al. (2013)

environmental services are a function of the broader environment (including climate and terrain) and thus not manageable at the typically, local to regional policy and land management scales. Ecosystem services are, however, a service provided by the ecosystem on the ground (vegetation, soil, wetlands etc) and thus can be manipulated by farmers, conservationists or others for both positive and negative ecosystem service delivery outcomes.

Cloud forest example

For example, the abundant water resources coming from headwater catchments in the humid tropics (see Saenz and Mulligan, 2013) are largely a function of the fact that tropical mountains receive a lot of rainfall and are subject to low ambient temperatures and low solar radiation, all as a function of their elevation. These are environmental services that are outside of the control of a land manager. On the other hand, cloud affected forests that occur in some of these mountain zones receive additional inputs of water through the capture of passing ground level cloud (fog) as cloud water interception (Bruijnzeel et al., 2011). This additional water is not captured when cloud-affected forests are replaced by shorter stature land cover such as pasturelands: this extra input of water is thus an ecosystem service that can be managed by managing land use. In managing ecosystem services we must therefore focus on managing the manageable: the ecosystem services and not the environmental services that are outside of the control of the typical decision-maker. Just because a clouds forest occurs in a wet climate does not the forest produces all of the water received.

River example

The amount of water present in rivers is largely a function of the magnitude and distribution of rainfall its flow above and below ground to the river network, and then transmission along the network conditioned by the network geometry and associated storages and transmission losses. The magnitude and distribution of rainfall, the nature of subterranean aquifers and the form and geometry of the river network are environmental processes that have little to do with the presence of specific ecosystems or land covers.

The much smaller fluxes of rainfall interception, evapotranspiration and infiltration into soil are associated with ecosystem structure. The key factors controlling river flow can thus be considered environmental services that are not easily managed (or mis-managed) by human activity, rather than ecosystem services which can be managed.

Table 11.1 provides a more comprehensive list of the ecologically-dependent goods and services associated with river systems. It is a clear that a gradient exists between generic and specific processes, components and services, and that, despite the longer listing here of services, many of these are directly manageable, or at least, subject to manipulation in an effort to effect a desired response in ecosystem behaviour Crucially, some of the entries in fact, depend on human agency - they are, in a sense, hybrid products of natural and modified systems; many are now subject to local manipulation, with less reliance on bounding, natural environmental controls.

[insert table 11.1 here]

The Brisbane declaration on environmental flows, freshwater systems and environmental sustainability (2007) further emphasises the dynamic, and hybrid nature of the environment-ecosystem services gradient. Climate change and human intervention have increased the pace and scale of ecosystem degradation in response to changing environment at ever-increasing scales, but with recognition of this, have also facilitated the scope and ambition of freshwater protection and remediation efforts. A key issue, then, arises as to the degree to which potential services are realised, and to which improved management might lead to further realisation of this potential

Potential vs. realised ecosystem services

Ecosystem services are, by definition, those services that are realised as benefits but not all potential services are realised, and it is important to understand the distribution of potential ecosystem services as well as realised services since the the addition of people, infrastructure or agriculture to an area soon realises more of the potential services. The relationship between potential and realised services differs between service-types. For carbon storage and sequestration all potential service is realised since all carbon storage and sequestration benefits the global carbon balance and thus the global beneficiaries of a regulated climate. For water provisioning services, as Table 11.1 illustrates, whilst the presence of a particular ecosystem can lead to the delivery of more or better-quality water downstream, this potential service is not realised as a benefit unless that water is used directly by populations, infrastructure or agriculture downstream or indirectly through its support of fisheries etc. If there are few people and little human development downstream the realised service will be a fraction of the potential service. Similarly for hazard mitigation services to be realised, there needs to be exposure to risk and the provision by ecosystems of hazard mitigation potential (e.g. wetlands providing storage that mitigates flood risk downstream). If the risk of flood does not exist in the area of the wetlands, or if there is no human exposure to any risk that does exist then the potential hazard mitigation is never realised. The cultural service of nature-based tourism has potential where high aesthetic value, well-preserved, rare, species rich and/or dramatic environments exist but it is only when these environments are (easily) accessible to an interested population with disposable time, income and means of travel that this service is realised.

Ecosystem Dis-services

We cannot discuss ecosystem services without also highlighting that ecosystems are not always good for us: globally more people die from wild species (most often diseases) than of all other causes combined (Dunn, 2010). So-called ecosystem dis-services are thus “functions of ecosystems that are (or are perceived) as negative for human well-being” (Lyytimaki and Sipila, 2009). These ecosystem dis-services can be classified as:

(a) Ecosystems negatively impacting human health, for example, wetlands providing habitat for malarial mosquitoes. Pathogens and the vectors that carry them are most speciose in the same tropical megadiversity countries in which most species occur and on which international conservation agendas are most focused. However, the dis-service (disease prevalence) is not greatest in the most pristine, diverse habitats but rather in disturbed habitats. According to Dunn (2010) we appear to make habitats worse for us in terms of their dis-services i.e. agricultural land harbours more pathogens and their vectors than more pristine environments (Schmidt & Ostfeld 2001, Vanwambekeet al. 2007). Or maybe this a case of already potential dis-services becoming realised in the presence of greater human populations.

(b) Species causing damage to production such as crop and livestock damage by pests and wild animals (De Boer and Baquete, 1998; Rao et al., 2002).

(c) Species generating nuisance (DeStefano and Deblinger, 2005), natural areas that generate feeling of fear, presence of large carnivores that cause a feeling of insecurity, and insects that cause discomfort.

We may also consider a series of environmental dis-services over which we have little control meteorological extremes leading to floods, droughts, freezes and heat waves; coastal surges; volcanic eruptions and earthquakes. In some cases, ecosystem dis-services may be an economically more viable reason for conserving wild lands than are the services (Dunn, 2010). Moreover, sustainable development must involve the management for sustainable ecosystem service provision and sustainable ecosystem dis-service minimisation.

Ecosystem service paradoxes for conservation

Conservationists expect ecosystem services to deliver significant conservation benefits with most of the large international conservation NGOs working and publishing on applications of the concept towards their conservation agendas. Unlike many other conservation prioritizations based on taxon specific biodiversity (Important Bird Areas - IBAs; Birdlife International 2012), or endemism (Endemic Bird Areas - EBAs; Birdlife International 2015), wilderness areas (Sanderson et al., 2002), high biodiversity threatened areas (Conservation International's hotspots; Myers et a;., 2000), uniqueness of habitat (WWF's Global200 ecoregions; Olson et al., 1998), ecosystem service approaches prioritise the utility value of the services provided not just the existence value of those services. Thus an area with very high potential service provision is not of high ecosystem service value unless those services are realised.

Deforestation leads to greater ecosystem services

Paradoxically for the conservation organisations, the ecosystem service value of a forest can be increased by its deforestation. Whilst this may reduce its value to global beneficiaries (for carbon sequestration and biodiversity), the consequent increase in local population, infrastructure and agriculture, increases the proportion of potential services for water provision and hazard mitigation and well as a range of other provisioning and regulating services that are realised. A remote forested wilderness provides few locally realised ecosystem services whereas the same geographical extent of forest upstream of a city can provide similar globally realised carbon and biodiversity services as well as significant locally realised water, hazard mitigation and nature based tourism services, amongst others. The ecosystem services framework will certainly help protect peri-urban environments and the watersheds of dams (Saenz and Mulligan, 2013) but will do little to protect the most remote, speciose wilderness areas of the world where the realised value of the goods (oil, minerals, forest plantations, agriculture) generated by conversion will invariably be greater than the realised value of the ecosystem to its remote users.

River restoration science - and emerging intervention practice

The increasingly widespread practice river restoration provides a further illustration of the paradoxes arising from management intervention crossing the environmental-ecosystems continuum. River restoration is itself a dynamic, evolving and global environmental intervention practice, which has multiple objectives, only some of which are focused on ecosystem improvement (Smith et al., 2014). Moreover, only some restoration interventions can be clearly framed in terms of close match between the type of restoration activity and environmental context and controls (Smith et al., 2013), and even the a biotic (hydrological and geomorphological) principles which are assumed to control the ecological performance of the intervention are frequently of questionable robustness (Clifford et al., 2008; Clifford, 2012). River restoration is then, at best, an immature and uncertain science (see Darby and Sear, 2008). From an ecological and ecosystems point of view, the large majority of documented case studies illustrate failure, rather than success (Ormerod, 2004): 'restoring' the physical abiotic conditions in a river less frequently lead to predicted, desired ecological benefits: rather, invasive and exotic species exploit the new habitat more quickly and more productively whether plants or fish. Such lack of success exemplifies a further paradox: that an increasingly popular environmental intervention seems to lack a reproducible science base, evaluated against a clear metric of environmental and ecosystem value. The paradox might partially be resolved when considering that many 'restorations' lie, in reality, on a spectrum of management intervention more appropriately characterised as 'rehabilitation' or 'remediation' where the management intervention either returns the trajectory of the system towards and original or to a new ecosystem state, as measured in terms of biomass and structure (Bradshaw, 1996).

Use of the term trajectory is itself of significance, since the time frame over which success or failure is measured also becomes crucial. Given also that river restoration is increasingly undertaken as part of a community-building citizen and participatory science agenda (Clarke, 2002; Clifford, 2012) then, as discussed in Section 1.1 and illustrated in Table 11.1, both the range of services arising from, and the associated metrics of valuation associated with, any intervention are also subject to change, evolution and to diversification away from narrower concerns with the fundamentals of ecosystem dynamics. Intervention into ecosystems is thus subject to multiple uncertainties transcending the traditionally 'scientific'.

[insert figure 11.1 here]

Necessary for sustainable development?

To be truly sustainable, development must be environmentally, economically, socially and politically sustainable. The ecosystem services concept allows us to break the sustainable development problem down into a series of services for which we can develop management strategies and policies that are designed to ensure that the ecosystem services are - and continue to be - provided as development progresses. The ecosystem structures and processes which help deliver each service - and the dependence of beneficiaries on the benefits supplied - can be studied. Development can then be managed to provide the necessary resource without undermining this service. In theory, service levels can then be monitored to ensure that the management objectives are met.

Technological vs ecosystem-based development

In most cases ecosystem services can be delivered by the natural green infrastructure or the same services can be engineered through so -called 'grey' infrastructure. For example, a seasonally regulated flow regime can be achieved by catchment management that retains forests and other well managed lands to encourage infiltration and slow seepage of water into sub-surface flows that contribute better to dry season baseflows. Alternatively, where this regulation service is no longer provided by the ecosystem, dams can be engineered to store wet season flows and thus maintain water supplies in the dry season. Maintaining green or developing grey infrastructure both have associated costs and political constraints. To maintain catchment infiltration rates by retaining forest lands there is an opportunity cost to agricultural development. To maintain infiltration under agriculture requires careful land management (terracing, tillage) and this has associated economic costs (but also potential co-benefits for agricultural productivity). Alternatively, the building of dams incurs significant initial build costs and continuous maintenance costs, alongside co-benefits in the development of new fisheries, recreational areas and hydropower sources, for example. These costs and benefits are not simply economic but also political.

The relative cost-effectiveness of green *vs.* grey infrastructure will depend upon their relative requirements for land (land use cost), labour and financing require as well as their effectiveness at maintaining the (ecosystem) service of interest under normal and abnormal (extreme) conditions. Green infrastructure tends to require less initial investment and lower maintenance costs and institutional capacity (it largely 'looks after itself') but may require significantly more land and could be less effective at maintaining particular services than the grey equivalent. The extent to which green or grey is better will depend on local availability of land, finance, land and institutional and organisational capacity. Existing green infrastructure may not always be in the places that the services provided are used *i.e.* it may provide potential but not realised services. Where services are required (*e.g.* upstream of urban areas subject to flooding), if green infrastructure such as wetlands providing flood storage do not already exist we have the option of developing new green infrastructure (restoring the green infrastructure that has been removed) or building new grey infrastructure. Design 'with nature' (McHarg, 1971) is likely to be more sustainable than design without it. Though there is an increasing body of literature on green infrastructure, this is largely focused on providing recreational services within cities and management of urban drainage (Williamson, 2003; Benedict and McMahon, 2006; Wise, 2008; Pinceti, 2010). Much less is written on rural green infrastructure and the balancing of green and grey infrastructure Kambites and Owen (2006). Here we discuss examples of managing ecosystem services through green and grey infrastructure from both a field and a modelling context.

Water: grey to green infrastructure in Kumasi, Ghana

The nearly 17m tall Owabi dam near Kumasi, Ghana was built between 1928-32 (Tetteh et al., 2004) to supply water to the the growing city of Kumasi that had a population of nearly 24, 000 in 1921. Underestimation of the city's growth rate and under-investment in pipeline networks led to significant lack of supply and resulting water-related conflict as the city's population (estimated at 75, 000 by 1951) continued to grow (McCaskie, 2009). By 1957, the dam's catchment area had become an illegal; building site and was eventually designated as city electoral wards 21 and 22. By 2005, Kumasi's population was 1.4-2 million. An inspection in 2003 also revealed that the Owabi Dam was near to collapse (McCaskie, 2009)

The dam now supplies only 20% of Kumasi's needs as the city, now Ghana's second city, has grown to a population of 2-3 million and has spread to cover almost all of the dam's catchment. The nearby Barekese dam supplies much of the remaining water demand, though the supply situation is far from optimal. The Owabi forest reserve around the dam is posited to help secure the catchment's water resources and prevent sedimentation but the reality is that with an almost entirely urban catchment (see figure 11.2) the reservoir is now highly prone to sedimentation and the forest reserve is unlikely to affect this since sediment originating in the urbanised catchment will enter the reservoir through the rivers and the forest will do little to reduce this. The forest reserve may, however, reduce wastewater contamination in what would otherwise be urban land.

Circumstances change: just because a dam is built for water supply does not mean it has to always be so. Thinking more broadly through an ecosystem service lens perhaps it is better to let this reservoir fill with sediment as an urban wetland that forms part of the city's sanitation system and an urban recreational asset and focus resources that would have been used to dredge this reservoir on management of the dominantly rural catchment of the Barekese dam in the north to increase its contribution to supply from 80 to 100%. The urbanisation of the Owabi dam catchment is a clear example of how not to develop sustainably. Replacing natural ecosystems with poorly managed agriculture and urban areas, alongside poor wastewater management practices significantly reduces the capacity of the reservoir to supply high quality water. Allowing this to happen at the same time that demand for water increases dramatically is particularly dangerous. However, given the illegal nature of much of the urbanisation, the huge rate of urban growth and the desperate poverty of many of the incoming migrants it is unclear how this situation could have been avoided through a greater focus on development through an ecosystem services lens. Development in Kumasi has been sustainable to the extent that the huge population growth rate has been sustained, even with little attention to the implications for hydrological ecosystem service provision. Sustainability so far has been propped-up by grey infrastructure development (of the Barekese reservoir). A more environmentally sustainable alternative may have been to continue to protect the Owabi catchment but then where would the nearly 3 million people have lived and what would have been the political ramifications? Ecosystem service management is necessary to sustain development but in cases like this - where change is rapid and massive - it is not sufficient and sustained development can only be achieved through the management of grey infrastructure.

[insert Figure 11.2 here]

Water treatment vs. Eco-efficient agriculture

The necessity of managing ecosystems for improved water quality is critical if the world's increasingly urban populations are to be provided with sufficient quality of water. 84 % of the population in more developed regions and 57% in less developed regions are expected to live in urban areas by 2025 (Pacione, 2009). Whether we manage the hydrological services provided to these cities through investment in surrounding green infrastructure (forest protection and eco-efficient agricultural techniques

- see Keating et al., 2010) or grey infrastructure (water treatment), depends on the scale of eco-efficiency required to have an impact on the points at which urban supplies are sourced. This is determined at least in part by the distribution of peri-urban land uses. In Table 11.2 we use the WaterWorld model (Mulligan, 2013) and in particular it's human footprint on water quality (HF) metric (Mulligan, 2009) which examines the distributiom potential contamination of water based on the distribution of rainfall to human (polluting) land and natural (non-polluting) land covers. HF calculates the percent of water in each pixel that fell as rain on potentially polluting land uses (cropland, pasture, urban, roads, mining, oil and gas) upstream and thus the HF index varies from 0 to 100%.

By applying this metric to interventions in different contexts we can assess the extent to which these interventions are effective at improving water quality and some of the trade-offs associated with their implementation. We examine three interventions (water treatment, eco-efficient agriculture and agricultural set-aside) for two urban settings, the city of Cali, Colombia located in the highly agricultural Cauca Valley and the city of Kathmandu in Nepal. The study area for Nepal is a one degree square tile centred on 27.5N,85.5E and the study area for Colombia is a one degree square tile centred on 3.5N,-76.5W. The land cover and use context for these complex catchments are shown in Figure 11.3. Both urban areas are surrounded by a cropland mosaic with some forest and non-forest natural land. Cali also has nearby area of intensive pasture. Protected areas can be found near to both cities. These catchments are also highly variable in all of the climatic, land cover and use, terrain and population datasets that are used by WaterWorld.

The eco-efficient agriculture scenario is generated by reducing the unit-area footprint of all agricultural pixels from their default of 1.0 to 0.5, assuming reduced inputs of fertiliser, pesticides and herbicides. The water treatment scenario is represented as an improvement in water quality by 100% for all cells with population density greater than 10,000 persons/km^2 because water treatment is assumed to be present in urban areas only for the baseline. The agricultural set-aside scenario converts agriculture to protected forest on steep (>15 degrees), wet (>2000 mm/year rainfall) slopes. Full details of the WaterWorld scenario generator used for these scenarios can be found in Mulligan (2014) and van Soesbergen and Mulligan (2014).

We can see from the results of this analysis (Table 11.2) that (a) different interventions to improve water quality have different impacts on water quality; (b) the same intervention can have different impacts on urban *vs.* rural populations, (c) the same intervention can have different impacts at different sites and (d) the agricultural set aside scenario even leads to decreased water quality for some beneficiaries (because of reduced runoff - and thus reduced contaminant dilution - due to increased forest cover). The 'land use cost' of the intervention measured as the land area over which it needs to be applied and the effectiveness of that spend (measured as the population with improved water quality per unit cost) vary between interventions at the same site and between the same intervention at different sites. The most effective green infrastructure intervention is eco-efficient agriculture in Cali and in Kathmandu though the difference between the two green infrastructure interventions differs between the two sites. This means that even for simple ecosystem service management interventions there are no simple rules of thumb concerning which intervention is most effective, since this depends on the specific biophysical and socio-economic context including the spatial configuration of land uses and interventions in relation to the distribution of potential beneficiaries (population and urban areas). As a result detailed spatial analysis - case by case - is necessary to manage even single ecosystem services.

[insert figure 11.3 here]

[insert table 11.2 here]

Sufficient for sustainable development?

We have discussed, with examples, whether and how ecosystem service management is necessary for sustainable development, we now examine whether sustainability can be achieved through ecosystem service management alone. We first examine the difficulties of accounting for the trade-offs between services when intervening to manage a single service and then examine the implications of these difficulties for sustainable development through the management of ecosystem services.

Bundles of services and tradeoffs

In Table 11.3 we summarise some of the other ecosystem services and beneficiaries that will be affected by the interventions described. These are calculated by using the footprint of each intervention (the areas where the intervention occurs) to mask baseline maps for each of these properties and calculating the sum of the property within the intervention's footprint. Carbon storage is mapped after Saatchi et al (2011); carbon sequestration is after Mulligan (2008); cropland and pasture productivity combine Mulligan (2008), Ramankutty (2008) and Mulligan (2013); population is after Landscan (2007) and water quantity is according to the WaterWorld water balance (wind-driven rainfall plus fog and snowmelt minus actual evapo-transpiration).

We can see that the different interventions aimed at improving water quality have very different footprints and impacts on water quality (Table 11.3) but also directly affect the environment of different numbers of people, of productive land and of other ecosystem services (Table 11.2). The eco-efficient agriculture intervention, for example is enacted over a very large area of agricultural land. It thus affects a much greater population (47% in the Kathmandu area and 25% in the Cali area) than the set-aside or water treatment interventions. This is clear in the per-unit intervention area population affected of 34,000 for eco-efficient agriculture around Cali *vs.* 14,500 for agricultural set-aside (though in the case of water quantity populations downstream of the footprinted area must also be considered as they are water quality). The populations affected differ between cities according to the land use footprint of the interventions and the population distributions. The intervention may have positive or negative effects on the population aside from its effects on water quality (through for example reducing demand for water, energy and transportation of agricultural inputs which reduces the pressure on these services for other uses).

The interventions also have different footprints on the agricultural production landscape. Eco-efficiency is clearly targeted on agriculture so affects 100% of cropland and pasture productivity. The effect on productivity may be positive or negative depending on the outcome of the eco-efficient techniques - which are unknown here - but which will affect much of the productive land in one way or another. Agricultural set-aside is focused on steep wet slopes and thus affects much less of the population and agricultural land (which do not tend to occupy such areas). However, per-unit area this intervention has a greater potential for impact on carbon storage and sequestration than the eco-efficient agriculture intervention, since set-aside is focused on areas with higher storage and sequestration. In both cases, agricultural set-aside has a lower footprint but a higher per-unit area water quantity that could be affected by the intervention (again because of the focus on steep, wet slopes in which the higher rainfall leads to a higher water balance).

[insert Table 11.3 here]

Table 11.3 helps us to understand the trade-offs and the potential risks for other elements of sustainability of interventions associated with the management of one ecosystem service. The potential impacts on other services depend upon the spatial targeting of the intervention and the spatial relationships between biophysical and socio-economic characteristics of the region - and thus differ between these two regions.

Those risks may be positive or negative (i.e. co-benefits of the intervention may accrue or the intervention may lead to degradation of other ecosystem services or components of human well-being)

The grey infrastructure intervention here (water treatment) has a land footprint of close to zero and thus leads to very small changes in all of the examined services. Because water treatment is targeted on populated areas, some populations are directly affected i.e. water treatment will create a significant impact on the landscape in the areas where treatment plants are built, these are very small in relation to the other interventions which have large footprints and thus great potential for co-benefits or unforeseen dis-benefits of the intervention applied. Because of these tradeoffs, the complexity of managing all services that are required for true sustainability is likely to be beyond our current analytical capability. Ecosystem services thus provides the framework for sustainability but only if we have full understanding of how to manage these services holistically and sustainably.

Conclusions: ecosystem services as a tool for sustainable development

The ecosystem services lens can help connect the benefits received from nature by people (and the contribution to wellbeing that accrues) with development or conservation interventions in the landscape that may impact those benefits (positively or negatively). It thus provides the potential for developing an operational framework for sustainable development through the assessment and management of ecosystem services. Realising this potential is fraught with difficulties that result from our lack of data and understanding on: (a) the geographical distribution of ecosystem services; (b) the processes that drive these services; (c) the benefits that they provide and the contribution that these benefits make to wellbeing in different societal groups; (d) the impact of development and conservation upon these services and their sustainability, and - perhaps most importantly within the context of sustainable development - (e) the interactions and tradeoffs for other ecosystem services that results from interventions targeted at the management of one service.

Ecosystem services thinking has some contradictions with sustainable development for example, increases in realised ecosystem service provision can be achieved through population growth, infrastructural and socio-economic development that create new beneficiaries that did not exist before. This increases ecosystem service provision - and may do so sustainably - but at the cost of biodiversity and other natural capital that may not provide a direct service and is thus not accounted for in the ecosystem services framework.

Ecosystem services can be sustained through the management of green infrastructure, the development of grey infrastructure or both. Green infrastructure is environmentally more sustainable since it is inherently ‘self-managing‘ but socio-economically placing large areas of land under set-aside, for example, may not be socio-economically as sustainable as, for example, building a water treatment plant. This may be true both in terms of the much higher land-use cost of the green infrastructure intervention and because of the associated potential risk of dis-benefits for other ecosystem services in the intervened areas. Where co-benefits can be achieved the green infrastructure intervention will be more sustainable but ensuring that only co-benefits result from an intervention is difficult.

Though the concepts and the rhetoric are well developed - we remain very naive in our ability to measure, understand and map even single baseline ecosystem service, even-less understanding impacts of management interventions and background scenarios for (climate) change, for example. Sustainable development requires the concurrent management of multiple ecosystem services that are relied on in different ways by many different socio-economic groups and affected in complex ways by management interventions. We are a very long way from being able to achieve that. But do we really need to or can we achieve sustainable development through high level interventions focused on the precautionary principles and on basic changes in behaviour necessary for sustained development? We argue that in most cases keeping an eye on the big picture of sustainability will get us further than the micromanagement of ecosystem services, at least until we really know what and how to micro-manage. Ecosystem service thinking has its real value in the analysis of simpler, specific interventions for managing specific services in specific places (for example assessing green *vs.* grey infrastructure approaches to controlling sedimentation of a dam) rather than in advising the the much broader goals of sustainable development.

Tables

Functions	Ecosystem processes and components	Goods and services
Regulation functions	Maintenance of essential ecological processes and life-support systems	
Waste treatment	Role of vegetation and biota in removal or breakdown of discharges to rivers	Pollution control Reduction in full treatment costs
Nutrient regulation	Role of biota in storage and recycling of nutrients (N&P)	Maintenance of water quality Reduction of algal blooms
Biological control	Population control through trophic relationships	Balanced native populations Control of pest numbers (eg., European carp)
Habitat functions	Providing habitat for native plants and animals	
Refuges	Suitable living space for native plants and animals	Maintenance of biodiversity Sources for re-colonisation. Minimum population support

Nurseries	Suitable reproduction habitat	Maintenance of population numbers Natural recruitment
Complexity	Variety of niches to support complex communities	Resilient food webs Diverse ecosystem structure supporting long-term stability
Vertical structure	Floodplain inundation and riparian growth	Vertical habitat, especially in arid zones Connected zones throughout catchments
Connectedness	Migration and dispersal throughout catchments	Catchment-wide maintenance of ecological communities via channels and riparian corridors
Production functions	Provision of natural resources	
Genetic resources	Genetic material, evolution and adaptation flexibility in native plants and animals	Adaptation to changed conditions because of use or climate change Chemical models and tools Test and assay organisms
Recreation	Sport fishing, aquarium plants	Populations with sufficient production for harvesting
Food	Commercial fishing and aquaculture	Harvestable populations Source material for aquaculture
Raw materials	Conversion of solar energy into biomass for human construction and other uses	Specialist riparian species—eg. river red gum
Functions	Ecosystem processes and components	Goods and services
Information functions	Providing opportunities for education and cognitive development	
Aesthetic value	Attractive landscapes	Enjoyment of scenery
Recreation	Variety in riverine landscapes	Travel and ecotourism Outdoor sports
Culture	Traditional people’s values and significance	Understanding the place and its value for long-term human habitation

Art	Natural features with artistic value	Nature as motive in books, film, painting, folklore, national symbols, advertising, and so on
History	Variety of features with value	Historical development of the country via rivers
Science and education	Variety in nature with scientific and educational value	Use of natural systems for education Use of nature for scientific research

Table 11.1 Ecologically dependent functions, goods and services of rivers. Source: Norrsi, Table 3.1.

	Land use cost (fraction of area)	(Change in) HF in all areas (%)	(Change in) HF in urban areas (%)	Population with improved water quality	Population with reduced water quality	(Change in) population exposed to HF>50%
Kathmandu						
Baseline	n/a	18%	61%	n/a	n/a	30000
Eco-efficient agriculture	64%	-7.1%	-0.49%	2.7M (42K/%)	0	-4800
Agricultural set-aside	22%	-2%	-0.044%	2900 (131/%)	340	-460
Water treatment	n/a	n/a	n/a	n/a	n/a	-3700
Cali						
Baseline	n/a	31%	75%	n/a	n/a	16000
Eco-efficient agriculture	61%	-14%	-14.4%	1.2M (20K/%)	0	-11000
Agricultural set-aside	17%	-1.7%	-1.6%	72000 (4200/%)	14000	-100

Water treatment	n/a	n/a	n/a	n/a	n/a	-2900

Table 11.2 Impacts of scenarios for ecosystem services management for water quality in Kathmandu, Nepal and Cali, Colombia.

	Carbon storage (% of total)	Carbon sequestration (% of total)	Cropland productivity (% of total)	Pasture productivity (% of total)	Population	Population (% of total)	Water quantity (% of total)
Kathmandu							
Eco-efficient agriculture	45 (0.7)	51 (0.8)	100 (1.56)	100 (1.56)	2200000 (34375)	46.81 (0.73)	50 (0.78)
Agricultural set-aside	18.57 (0.84)	18 (0.82)	12.31 (0.56)	13.85 (0.63)	320000 (14545.45)	6.81 (0.31)	21.67 (0.98)
Water treatment	0.06 (0)	0.1 (0)	0.15 (0)	0.03 (0)	230000 (0)	4.89 (0)	0.1 (0)
Cali							
Eco-efficient agriculture	42.11 (0.69)	56.04 (0.92)	100 (1.64)	100 (1.64)	920000 (15081.97)	26.29 (0.43)	42.86 (0.7)
Agricultural set-aside	23.16 (1.36)	16.48 (0.97)	4.36 (0.26)	5.71 (0.34)	25000 (1470.59)	0.71 (0.04)	24.64 (1.45)
Water treatment	0.03 (0)	0.07 (0)	0.13 (0)	0.11 (0)	4.86 (0)	4.86 (0)	0.05 (0)

Table 11.3 Ecosystem services that may be affected by footprint of water quality service management interventions. Figures in brackets are variable per unit land use cost of the intervention.

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Figure captions:

Figure 11.1 Original: Bradshaw, A. D. (1996) Underlying principles of restoration. Figure 1 .Can. J. Fish. Aquat. Sci. Vol. 53 (Suppl. 1), 1996 (modified by Breen & Walsh 1996 in Rutherfurd et al. 1999.)

Figure 11.2 The now-urbanised catchment of the Owabi dam (shades represent elevation) as described by the WaterWorld model (www.policysupport.org/waterworld).

Figure 11.3 Land use for the study areas around the cities of Cali (a) and Kathmandu (b) as described by the WaterWorld model (www.policysupport.org/waterworld). Int=intensive, Mos=mosaic.